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50'th anniversary of Industrial ELV Accelerators

The article highlights the 50-year development of ELV electron beam accelerators at the Budker Institute of Nuclear Physics for industrial applications. ELV accelerators are used primarily for radiation modification of polymers, such as cable insulation, and are known for their high reliability, ease of use, and adaptability to various industrial needs. The evolution of these accelerators is traced from early models with 20 kW power to modern versions reaching up to 100 kW, and even a unique 400 kW machine. The article also discusses the integration of automated systems and specialized equipment that enhance the efficiency and quality of radiation-chemical processes. Applications include a wide range of industries, from telecommunications to nuclear power, where reliability under harsh conditions is essential. Despite past challenges, such as economic disruptions, the production of ELV accelerators continues to thrive, with over 220 units delivered worldwide. The institute is focused on advancing these technologies to meet future demands.

Keywords: ELV accelerators, electron accelerators, industrial accelerators, cross-linking.

Introduction

Since 1971, the Budker Institute of Nuclear Physics, Siberian Branch of the Russian Academy of Sciences (BINP SB RAS), has been developing and producing ELV-type electron beam accelerators for use in industrial and research radiation technology installations. ELV-type accelerators are built using standardized systems and components, allowing cost-effective customization to meet specific customer requirements, such as energy range, electron beam power, beam window length, and so on. The design and circuit solutions provide for long-term, continuous, round-the-clock operation under industrial conditions. The distinct qualities of ELV accelerators include simplicity of design, ease of operation, and high reliability.

Status

Recently, it marked 50 years since the final testing of the ELV-1 accelerator as part of the interdepartmental commission program at the Experimental Plant of the All-Union Research Institute of Cable Industry in Podolsk. The commission was formed by the Ministry of Electrical Industry and included nine representatives: accelerator specialists (BINP and the Efremov Institute), the cable industry (VNIICP), radiation technology experts (VNIIRT and NPO PLASTIK), and the Ministry of General Engineering.

As a result of these tests, the commission recommended the accelerator for industrial use and mass production. The BINP immediately began fulfilling an order for 15 accelerators for the Ministry of Electrical Industry's enterprises. Today, the institute offers a series of ELV electron accelerators, covering an energy range from 0.3 to 4 MeV, with beam currents of up to 100 mA and a maximum power of up to 100 kW. The ELV accelerator is the most mass-produced and popular domestic accelerator. Since 1974, over 220 machines have been manufactured and delivered, with 120 of them still in operation. The oldest one installed abroad has been in the Czech Republic since 1980. We also work with partners in South Korea and China. It's worth noting that the Moscow Electromechanical Plant named after Vladimir Ilyich also produced ELV accelerators, but production was halted due to economic collapse, although several units were still made.

The energy range of the ELV family now covers from 0.3 to 4 MeV. The electron beam power reaches 100 kW, and there is a unique machine with a beam output power of 400 kW. It should be noted that the power of the first accelerators was only 20 kW, while today's 100 kW meets consumer demands, and there is no sharp increase in power expected. Figure 1 shows a diagram of a typical ELV, and Figure 2 depicts the most popular ELV-8 accelerator in China [1–3].

Applications

ELV accelerators are used in almost all radiation-chemical technological processes, but mainly for the radiation modification of various polymer products: cable insulation, heat-shrinkable tapes and tubes, the production of foam polyethylene, and more. The quality of the radiation treatment depends on both the accelerator itself and the technological equipment: systems for transporting products under the electron beam in the irradiation zone, take-up and pay-off devices, synchronization between the accelerator and the transportation equipment.

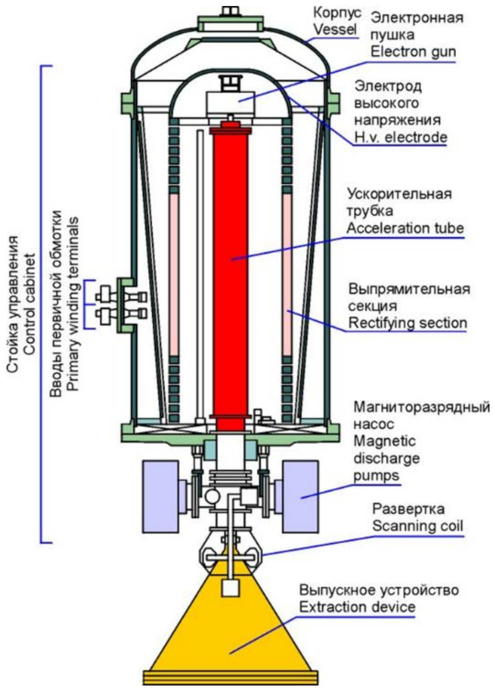

Figure 1. Common design of ELV accelrators

Figure 2. ELV-8 accelerator

The use of electron beam technology has enabled the production of a wide range of cables, wires, and heat-shrinkable products for various markets: power plants, telecommunications, electronics, the oil and gas, nuclear power plants, submarines, aviation, and railway transport. These industries require high reliability during installation and operation under harsh conditions and unusual situations. Therefore, great attention is given to improving productivity and the quality of electron beam processing.

Additionally, the accelerator and technological equipment are integrated into automated synchronized complexes. These complexes ensure impeccable quality of radiation modification across a wide range of energies and product types, as shown in Figures 3 and 4. Within the automated complex, it is possible to control both the accelerator via signals from the technological line and the technological line via signals from the accelerator. The interaction protocol between the accelerator and technological equipment is compatible with all technologies and equipment produced by various companies. Figure 5 shows the complex's control panel, and Figure 6 shows the produced products. In an automated complex, the operator does not need to be at the control panel. Process parameters are controlled automatically, and the operator can monitor them from various points in the technology hall without approaching the equipment. The time remaining before changing the processed reel is displayed on the control panel.

Key features of ELV accelerators:

- High beam power across a wide energy range, indicating high productivity of electron beam processing.
- High efficiency in converting electrical energy to accelerated electron beam energy. The efficiency ranges from 70 % to 90 %, depending on the power.
- ELV accelerators operate stably with energy and current fluctuations not exceeding +/-3 %.

- Simple control procedures due to an automated control system. This allows synchronization of accelerator operation with technological equipment, and the accelerator can be part of a fully automated technological line.
- The control system includes a comprehensive set of hardware and software covering all accelerator nodes requiring operational control, monitoring, and diagnostics.
- The accelerator itself has a simple design and high reliability.

Figure 3. Extraction device with four-side irradiation system equipped

Figure 4. Irradiation line in the South Korea company LG cable

In collaboration with EBTech (Electron Beam Technologies, South Korea), we developed a mobile ELV accelerator variant that can be moved along a track. This machine is housed in a trailer and equipped with local radiation protection. It can perform electron beam processing of liquids, gases, and bulk materials. It is shown in Figure 7. The energy of this accelerator is up to 650 keV, with a power of up to 30 kW. It has been transported within Korea and sent to Saudi Arabia, and returned after conducting experiments.

Together with the same company, a full-scale electron beam processing installation for dyeing wastewater was developed. It used an accelerator with a 400 kW beam power. The reaction chamber is shown in Figure 8. This accelerator uses 3 acceleration tubes and three output devices [3].

Figure 5. External status screen in the Podolsk cable plant

Figure 6. Irradiated production (India)

Beam extraction to the atmosphere through an aperture

A.M. Budker was an advocate for using accelerators in various sectors. He correctly believed that accelerator applications extend beyond radiation-chemical processes for polymer material modification. The thermal impact of a powerful focused electron beam can be utilized in metallurgical processes, cutting, welding, and working with inorganic materials. To release the focused beam into the atmosphere, an output device with a multi-stage differential pumping system is used. The electron beam is focused by magnetic lenses, and apertures are installed in its crossover for beam passage [3].

Continuous vacuum pumps evacuate gas entering through the apertures. Using a series of such chambers, the pressure is gradually reduced from atmospheric to the working pressure of the accelerating device. At the output of the device, the beam size does not exceed 1-1.5 mm, allowing a beam power density of 106 W/cm^2 or higher with 100 kW beam power. Figure 9 shows the glow of the concentrated beam released into the atmosphere. The decrease in brightness with distance from the output aperture is due to beam scattering in the air. Three versions of atmospheric beam release have been developed and produced: one for a magnetic focusing tube, one for a large-aperture tube, and one for adiabatically compressed electron beam output with up to 1 A current and 500 kW power [3, 4].

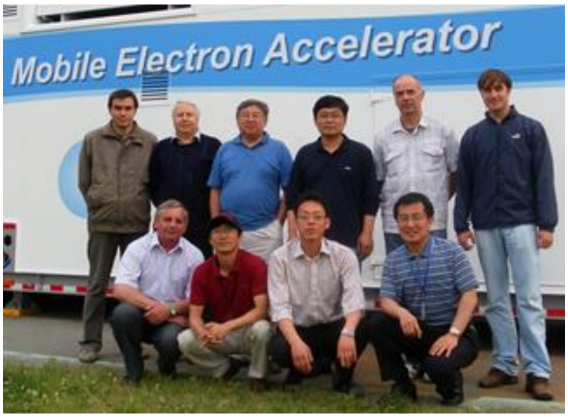

Figure 7. Russia-SouthKoreateam in front
of trailer with accelerator inside

Figure 8. Waste water treatment room
in the dying center. Daegu, South Korea

At the BINP, numerous successful experiments have been conducted on various materials (metals and alloys, rocks, ceramics, plastics, etc.) using the focused electron beam released into gas at atmospheric pressure. The beam has been released into both air and protective atmospheres (argon, helium). However, this beam release system has not found widespread application in industrial processes. Subsequently, this setup received the status of a unique scientific installation (USI). Currently, numerous experiments are being conducted with this accelerator, equipped with a focused beam atmospheric release system, in collaboration with various Soviet, Russian, and foreign organizations. These experiments include developing technological modes and obtaining valuable scientific results in steel hardening (including coating wear-resistant layers on copper plates for continuous steel casting), various radiation-thermal processes in solid-state chemistry (including technology for producing inexpensive high-activity ammonia synthesis catalysts from catalyst production waste), and developing high-performance methods for producing metal and oxide nanopowders by direct evaporation from melts, as well as other high-temperature technological processes [5].

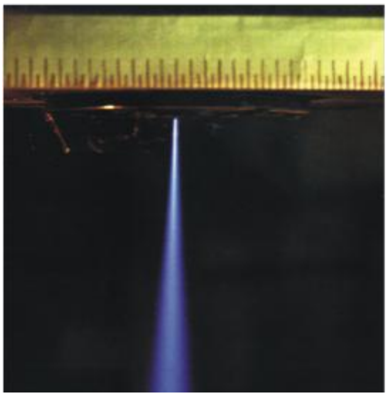

Figure 9. Electron beam extracted into the atmosphere

Conclusions

For more than 50 years, the Budker Institute of Nuclear Physics in Novosibirsk has been developing ELV industrial electron accelerators, which have found widespread use both in Russia and abroad. These accelerators have gained recognition for their high reliability, ease of maintenance, and adaptability to a wide range of technologies. Nevertheless, the institute continues to develop new types of ELV accelerators and modify existing models. The main goal of this activity is to be ready for future demands for accelerators with higher parameters, should new breakthrough technologies arise.

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ЭЛВ үдеткішіне 50 жыл

Мақалада Г.И. Будкер атындағы Ядролық физика институтының ЭЛВ өнеркәсіптік электронды үдеткіштерінің елу жылдық дамуы баяндалады. Негізінен ЭЛВ үдеткіштері полимерлерді радиациялық модификациялау үшін қолданылады (кабельді оқшаулау және т.б.) және жоғары сенімділігімен, пайдаланудың қарапайымдылығымен және әртүрлі өндірістік қажеттіліктерге бейімделуімен танымал. Бұл үдеткіштердің эволюциясы 20 кВт-тың алғашқы модельдерінен 100 кВт-қа дейін жететін заманауи нұсқаларға, тіпті 400 кВт-қа дейінгі бірегей машинаға дейін байқалады. Авторлар радиациялық-химиялық процестердің тиімділігі мен сапасын арттыратын автоматтандырылған жүйелер мен мамандандырылған жабдықтардың интеграциясын талқылайды. Қолдану салалары телекоммуникациядан бастап ядролық энергетикаға дейінгі салалардың кең ауқымын қамтиды, яғни мұнда қатал жағдайларда сенімділік өте маңызды. Экономикалық тоқырау сияқты бұрынғы мәселелерге қарамастан, ЭЛВ үдеткіш өндірісінің өркендеуі жалғасуда, бүкіл әлем бойынша 220-дан астам қондырғы қойылды. Институт болашақ қажеттіліктерді қанағаттандыру үшін осы технологияларды ілгерілетуге бағытталған.

Кілт сөздер: ЭЛВ үдеткіштері, электронды үдеткіштер, өнеркәсіптік үдеткіштер, біріктіру.

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50 лет ускорителям ЭЛВ

В статье освещается пятьдесят лет разработки промышленных ускорителей электронов ЭЛВ в Институте ядерной физики имени Г.И. Будкера. В основном ускорители ЭЛВ используются для радиационной модификации полимеров (кабельная изоляция и пр.), и известны своей высокой надежностью, простотой использования и адаптивностью к различным промышленным потребностям. Эволюция этих ускорителей прослеживается от ранних моделей мощностью 20 кВт до современных версий, достигающих мощности до 100 кВт, и даже уникальной машины мощностью 400 кВт. Авторами обсуждается интеграция автоматизированных систем и специализированного оборудования, которые повышают эффективность и качество радиационно-химических процессов. Области применения включают широкий спектр отраслей промышленности, от телекоммуникаций до ядерной энергетики, где надежность в суровых условиях имеет решающее значение. Несмотря на прошлые проблемы, такие как эко-

номические потрясения, производство ускорителей ELV продолжает процветать, по всему миру поставлено более 220 единиц. Институт сосредоточен на продвижении этих технологий для удовлетворения будущих потребностей.

Ключевые слова: ускорители ЭЛВ, ускорители электронов, промышленные ускорители, сшивка.

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